CHEMICAL and PHYSICAL PROPERTIES of SPOIL BANKS In The Eastern Kentucky Coal Fields

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What We Did

Spoil material was collected from 10 sample points, spaced a quarter of a mile apart, at each of 6 mining sites:

Seam	*Location*
Hazard No. 9	Knott County, Kentucky
High Splint	Harlan County, Kentucky
Low Splint	Harlan County, Kentucky
Harlan I[1]	Southeast Harlan County, Kentucky
Harlan II[1]	Western Harlan County, Kentucky
River Gem	McCreary County, Kentucky

The samples were taken from the surface 6 inches on the outslope of spoil banks. After air drying, material larger than 1 inch was removed. The remainder was screened through 2-millimeter-mesh sieves. The Bouyoucos hydrometer method was used to determine the percentage of sand, silt, and clay in the material passing the 2-millimeter sieve.

All chemical analyses were made on the material smaller than 2 millimeters. Soil pH was measured electrometrically with a Beckman glass electrode in a 1:1 soil-water suspension. Soluble salts were estimated from the electrical conductivity of a 1:2 soil-water extract. Conductance was measured using a conductivity bridge and conductivity cell. Organic matter content was determined using the method of Peech et. al. (1947) with the optional O-phenanthroline ferrous complex indicator (Lunt et al. 1950).

Spectrophotometer determinations of exchangeable calcium, potassium, magnesium, and sodium were made by the method described by Jackson (1958), using ammonium acetate. Exchangeable hydrogen was determined by the barium acetate titration method. Readily soluble phosphate was determined by the modified Truog method of Peech et al. Sulphate determinations were made by the turbidimetric method described by Jackson. Exchangeable ferrous and ferric iron was determined by a slightly modified method of Lunt et al. adopted for a spectrophotometer.

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[1]Both are spoils from the Harlan seam. The Roman numerals designate geographic locations.

Exchangeable manganese, aluminum, copper, zinc, chlorine, and molybdenum were determined colorimetrically by a commercial soil testing laboratory after extraction with a solution buffered to pH 5.0.

Physical Properties

The rock overburden for all coal seams in this study is sedimentary, dating from the Pennsylvanian period. Sandstones and shales in various proportions predominate. Irregularly interspersed are thin-bedded coal seams. The mined coal seam is occasionally divided by one or more slate binder layers. The natural soil above the rock overburden is generally shallow.

Spoil banks are a mixture of rock fragments (composed of various minerals) ranging in size from massive chunks to sand, silt, and clay-sized particles. For this analysis only the smaller rocks (those passing a 1-inch screen) and the soil fraction were considered since these are more closely associated with soil-plant relations. Most of the spoil material is smaller than 1 inch.

By air-dry weight, approximately 60 percent of the material passing a 1-inch-mesh sieve was less than 2 millimeters in size. This percent ranged from 47 on the Harlan II spoil to 67 on the Harlan I and Low Splint spoils.

The soil fraction, material smaller than 2 millimeters, averaged 42 percent sand, 29 percent silt, and 29 percent clay. The Harlan I, Hazard No. 9, Low Splint, and High Splint spoils were classified as clay loams; the Harlan II and the River Gems, as loams.

Chemical Properties

Acidity

Soil pH is a measure of acidity or active hydrogen ion concentration. In growth media, such as agricultural soil and spoil banks, it is important because the solubility and availability to plants of many important nutrients are closely related to soil pH. Generally, as the pH decreases below 4.5, toxic ions come into solution and some essential nutrients become less available to plants.

All the spoil-bank samples had a lower pH than most agricultural soils, but not all were toxic. The spoils would be classified as medium acid to extremely acid according to the Soil Survey Manual (U.S.-D.A., 1957); the pH ranged from 2.2 to 5.7; and the acidity at 60 percent of the points indicates revegetation can be accomplished. The pH values for the samples from the Harlan II seam were significantly higher than those from any other seam. They ranged from pH 4.3 to 5.7.

Ranking the area sampled on each of the spoils by Limstrom's (1960) five acidity classes, the High Splint, River Gem, and Harlan I were toxic; the Hazard No. 9 and the Low Splint were marginal; and the Harlan II was acid.

Soluble Salts

If the concentration of total soluble salts is high enough, it may interfere with seed germination, plant growth, or plant intake of water. Jackson states that in a 1:2 soil-water extract, a specific conductance of 1 millimhos per centimeter may be critical for germination, 2 millimhos per centimeter is critical for the growth of some salt-sensitive plants, and 3 millimhos per centimeter may result in severe plant injury. In this case, 13 percent of the sample points had a specific conductance over 1 millimhos per centimeter, 6 percent over 2 millimhos per centimeter, and 3 percent over 3 millimhos per centimeter. So at 87 percent of the sample points soluble salt concentration was not high enough to be deterimental to most plants. The highest average concentrations were found on the High Splint spoils where the specific conductance ranged from 0.1 to 4.9 millimhos per centimeter.

Organic Matter

In agricultural and forest soils, organic matter is often used as an indicator of fertility. On spoils, coal fragments and other carbonaceous materials will react as organic material, yet they do not contribute available nutrients. Therefore, the percentage of organic matter in a spoil is a questionable indicator of fertility.

In these spoils, organic matter ranged from 0.6 to 7.4 percent. Thirty-five percent of the samples had 4 percent or more organic matter, an average Brady and Buckman (1960) believe is representative of forest soils in the humid southeastern United States. The Harlan I samples had the highest average percentage of organic matter.

Cation-Exchange Capacity and Percent Base Saturation

Cation-exchange properties of soil originate in the clay and the organic matter. In the agricultural soils of this region, cation exchange ranges from 17 to 30 milliequivalents per 100 grams. On these spoils the cation-exchange capacity ranged from 5 to 27 milliequivalents per 100 grams (table 1). The highest exchange capacity occurred on the Hazard No. 9 and the Harlan II spoils where values ranged from 11 to 27 milliequivalents per 100 grams. The River Gem spoils had the lowest range of values—5 to 11 milliequivalents per 100 grams.

TABLE 1.—The range and mean for the cation-exchange properties at all sample points

	Mean	Range	
		High	Low
Cation-exchange capacity (milliequivalents/100 grams)	12.44	27.5	4.7
Base saturation (percent)	53	81	32
CONTRIBUTION OF THE ELEMENTS COMPOSING CATION-EXCHANGE CAPACITY			
Calcium (milliequivalents/100 grams)	1.85	7.80	0.15
(percent of cation-exchange capacity)	14.5	34.2	2.1
Magnesium (milliequivalents/100 grams)	4.21	8.33	0.99
(percent of cation-exchange capacity)	34.1	58.8	16.0
Potassium (milliequivalents/100 grams)	0.23	0.42	0.06
(percent of cation-exchange capacity)	2.1	4.6	.4
Sodium (milliequivalents/100 grams)	0.37	0.67	0.15
(percent of cation-exchange capacity)	3.3	12.7	1.4
Hydrogen (milliequivalents/100 grams)	5.75	16.41	1.90
(percent of cation-exchange capacity)	46.0	67.5	18.8

Base saturation is the percentage of the cation-exchange capacity saturated by calcium, magnesium, potassium, and sodium. Seventy-two percent of the samples had a base saturation below 60 percent, a level considered low on local agricultural soil. There was no significant difference in base saturation between spoils.

The cations of most interest in soil fertility are hydrogen, calcium, magnesium, potassium, and sodium. In the spoil samples we found deficiencies of some of these nutrients and an imbalance between calcium and magnesium that could retard plant growth. Exchangeable calcium was low to very low on all spoils, ranging from 0.2 to 7.8 milliequivalents per 100 grams and representing 2 to 34 percent of the cation-exchange capacity. Bear and Toth (1948) state that calcium should contribute 65 percent of the exchange capacity for the optimum growth of alfalfa.

Magnesium, on the other hand, was abundant on all spoils. We found magnesium concentrations ranging from 1 to 8 milliequivalents per 100 grams which represented 16 to 59 percent of the total-exchange capacity. These values in themselves may not cause problems in plant growth but where there is more exchangeable magnesium than calcium, plant growth may be reduced. Generally, the amount of exchangeable calcium should at least equal and preferably exceed the amount of exchangeable magnesium. But on these spoils more exchangeable magnesium than calcium was found in 93 percent of the samples.

Potassium usually contributes 1 to 3 percent of the exchangeable cations in agricultural soil ("Soil," U.S.D.A. 1957). On the spoils, 90 percent of the sample points had over 1 percent exchangeable potassium and 20 percent had 3 percent or more. Using local agricultural soil as a criterion, 30 percent of the samples were deficient in potassium.

Sodium, although not an essential plant nutrient, was abundant on all spoils. It occupied from 1 to 3 percent of the total-exchange capacity.

Exchangeable hydrogen represented 19 to 67 percent of the cation-exchange capacity. In 30 percent of the samples, exchangeable hydrogen accounted for 50 percent or more of the exchangeable cations. It is difficult to interpret the significance of exchangeable hydrogen in terms of plant growth because the analytical method used measures hydrogen ions from several sources; viz., hydrogen ions in solution or absorbed in colloids, hydroloysis of exchangeable aluminum and iron, and ionization of organic matter.

The Availability of Other Elements

Several other elements play an important part in plant nutrition. Others have a rather obscure but necessary role in the growth and development of plants. Many of these can injure or kill a plant when they are present in high concentrations. This toxicity may be the direct result of the presence of high concentrations of an element or the indirect result of its replacing some similar but essential element.

Available phosphorus, extracted from the samples with a weak acid, ranged from 1 to 170 parts per million (table 2). Sixty percent of the samples had concentrations of 5 parts per million or more. The Harlan II spoils had significantly more available phosphorus than the other spoils.

TABLE 2—The ranges and means of elements other than Ca, Mg, K, Na, H of all sample points

	Mean	Range	
		High	Low
	Parts per million	Parts per million	Parts per million
Phosphorus	32	170	1
Iron[1]	104	619	13
Manganese	37	205	2
Aluminum	6.1	26.6	.2
Sulphates	1,313	6,500	50
Copper	18.2	27.8	1.3
Zinc	14.2	18.1	9.0
Boron	.17	.20	.15
Chlorides	2.3	33.2	.2
Molybdenum	.058	.188	.005

1/ Ferrous and ferric iron combined.

Zinc, boron, copper, molybdenum, and the chlorides were found in amounts considered adequate but not toxic for plant growth. There was no significant difference in the chloride concentration among spoils. However, we did find significant differences in the amounts of zinc, boron, copper, and molybdenum.

Available iron, manganese, aluminum, and sulfur were present in high concentrations at several points. Some of these concentrations may be toxic to some plants. It is difficult to define a toxic concentration because of the complex interrelations between nutrients and the variation in the tolerance of different plant species. The highest concentrations of all four elements were found on the extremely acid High Splint spoils. The following were the maximum concentrations encountered: iron, 619 parts per million; manganese, 205 parts per million; aluminum, 27 parts per million; and sulfur, 6,500 parts per million. The maximum concentrations at the acid Harlan II spoils were: iron, 104 parts per million; manganese, 34 parts per million; aluminum, 3 parts per million; and sulfur, 900 parts per million.

Plantability

The preceding information is of interest to someone who is investigating plant growth in this unique growth medium. But to the man planning revegetation the data may be confusing and difficult to interpret. He wants indicators, rules of thumb, for determining which spoils can be revegetated.

The pH is often so used because it can be easily and reliably determined with inexpensive materials and equipment. Limstrom's (1960) five acidity classes summarize years of observation regarding the effects of pH on tree growth. Using these classes and our data, we would consider the Harlan II plantable; the Low Splint and Hazard No. 9 marginal; and the High Splint, Harlan I, and River Gem not plantable.

Since high concentrations of the toxic ions—iron, manganese, aluminum, or sulfur—are related to high specific conductance on acid spoils, this may be another indicator of plantability. Specific conductance can be determined in a laboratory with moderately priced equipment. Assuming that a specific conductance of 1 millimhos or less per centimeter is plantable, 2 millimhos per centimeter is marginal, and 3 millimhos per centimeter is toxic; the Harlan I, Harlan II, Low Splint, and River Gem are plantable; the Hazard No. 9 is marginal; and the High Splint is toxic (table 3).

TABLE 3.—Spoil bank plantability as individual by pH and specific conductivity

Spoil	pH		Specific conductance		Mean physical and chemical characteristics						
	Mean	Plant-ability[1]	Mean	Plant-ability[2]	Clay	Organic matter	Cation-exchange capacity	Iron	Manganese	Aluminum	Sulfur
			Millimhos per centimeter		Percent	Percent		Parts per million	Parts per million	Parts per million	Parts per million
Hazard No. 9	3.82	Marginal	0.9	Marginal	28	3.8	18.0	59	32	4	194
High Splint	3.33	Toxic	1.7	Toxic	30	2.2	14.6	282	78	13	3,020
Low Splint	3.85	Marginal	.8	Plantable	34	3.9	12.4	67	23	5	704
Harlan I	3.74	Toxic	.3	Plantable	28	5.9	11.6	101	8	6	585
Harlan II	5.03	Plantable	.2	Plantable	26	2.3	10.0	42	19	1	455
River Gem	3.55	Toxic	.5	Plantable	25	1.8	8.0	78	54	7	1,180

1/ pH Plantability Standards

Toxic--70 percent or more of samples with pH values less than 4.0.

Marginal--50 to 70 percent of the samples with pH values less than 4.0.

Plantable--More than 50 percent of the samples with pH 4.0 or over.

2/ Specific Conductivity Plantability Standards

Toxic--70 percent or more of samples with specific conductance of 1 mmhos/cm or more.

Marginal--50 to 70 percent of samples with specific conductance of 1 mmhos/cm or more.

Plantable--More than 50 percent of the samples with specific conductance of 1 mmhos/cm or less.

The two indicators do not agree on the plantability of the spoils. The pH indicates that one spoil is plantable, two marginal, and three not plantable; whereas specific conductance indicates that four are plantable, one marginal, and one not plantable. A comprehensive analysis of vegetative yields on spoil material with various pH and specific conductance values must be made before we can say which is the better indicator of plantability.

Discussion

This is the first part of a study to determine some chemical and physical properties that may affect plant growth on spoil banks in the eastern Kentucky coal field. The results may not typify this coal field but they do provide a basis for prelminary evaluation of revegetation prospects.

Physical analyses showed that most of the material passing a 1-inch-mesh screen is less than 2 millimeters in size. The soil fraction of individual spoils was classified either as loam or clay loam. Soil of this texture generally favors plant growth.

The base saturation was low. In particular, exchangeable calcium was low to very low. Exchangeable magnesium was abundant on all spoils and generally more abundant than calcium. This imbalance could adversely affect plant growth and development. Low to adequate amounts of exchangeable potassium were found on these spoils.

Available phosphorous was found in adequate amounts on more than half of the sample area. We believe that the concentrations of copper, zinc, boron, molybdenum, and the chlorides found were too low to be toxic to plants.

Concentrations of available iron, manganese, aluminum, and sulfur that we suspect are toxic to many plants were found on several spoils. However, we need to define the toxicity levels for each of these elements and determine for a range of plants the tolerance to high concentrations of these elements.

Our analyses indicate that a majority of the sample points on these six spoils will support plant life. However, for many spoil areas, we need plants that will tolerate acidity, have low calcium requirements, and tolerate high concentrations of iron, manganese, aluminum, and sulfur. By careful selection or breeding we expect to find plants that will grow on spoils with a pH of 3.5 to 4.0. It is questionable if any plants will grow where the pH is 3.0 to 3.5, and we are certain no plants will grow below 3.0. Extreme acidity can be prevented in the future by spoil placement during mining or regrading after mining to bury the extremely acid material. Existing toxic banks will be carefully studied to determine if weathering will modify the condition in time, or if supplemental treatments must be applied to chemically neutralize the toxic ions. In these ways we should be able to assure the successful establishment of plants within a reasonable time after mining.

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